

***Orbital***



# **Thermal Vacuum Tests of GLAS Propylene Loop Heat Pipe Development Model**

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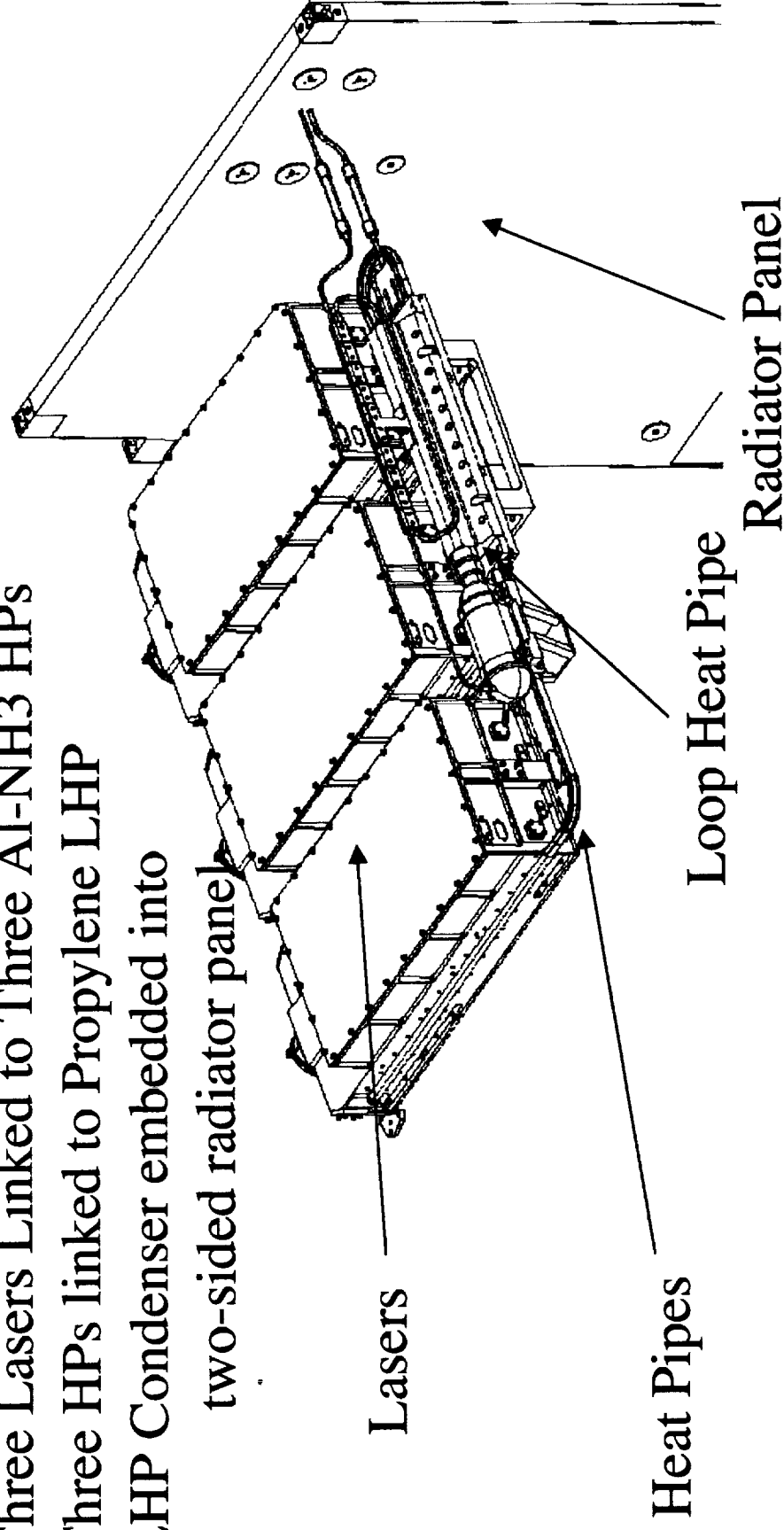
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# Flight LHP System (Laser)

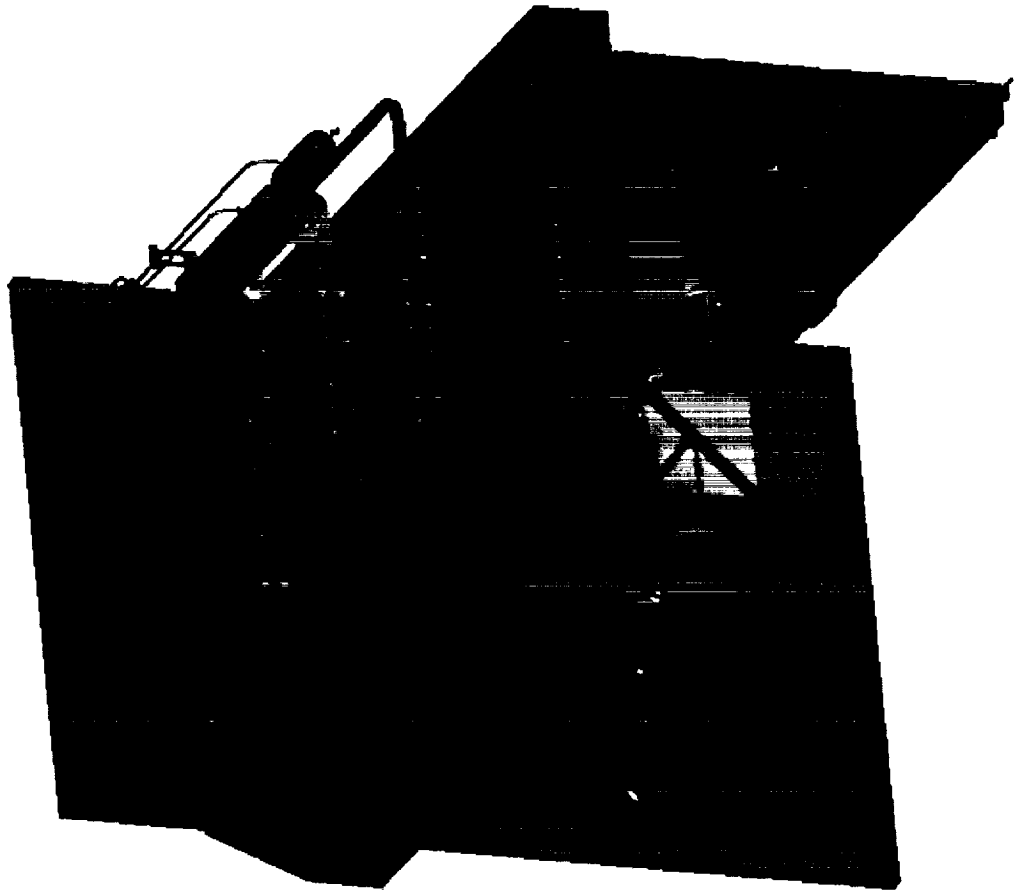
- Three Lasers Linked to Three Al-NH<sub>3</sub> HPs
- Three HPs linked to Propylene LHP
- LHP Condenser embedded into two-sided radiator panel





# Flight LHP System (Laser)

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# Test Design and Objectives

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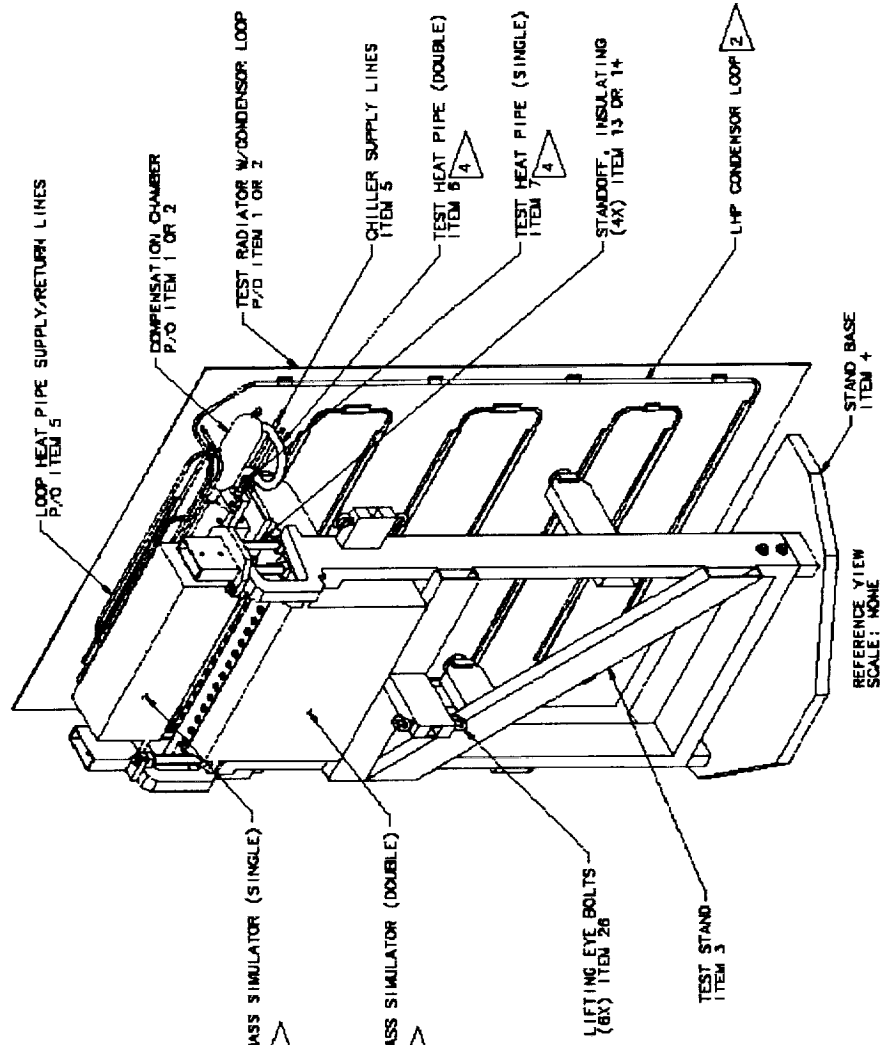
## •Test Design

- Conductively isolate all components from the Test Stand (G10 spacers, minimize the Temperature Difference by Heating Stand)
  - Radiatively isolate all components from each other with MLI
  - Use heater plates to control sink for both sides of radiator
  - Test Objectives for Both Hot and Cold Cases
    - Demonstrate LHP system startup and operation with propylene
    - Demonstrate LHP Temperature Control
    - Measure Control Heater Power with On/Off Controller and Liquid-Vapor Line Coupling blocks
    - Compare Adverse to Reflux Orientation Operation
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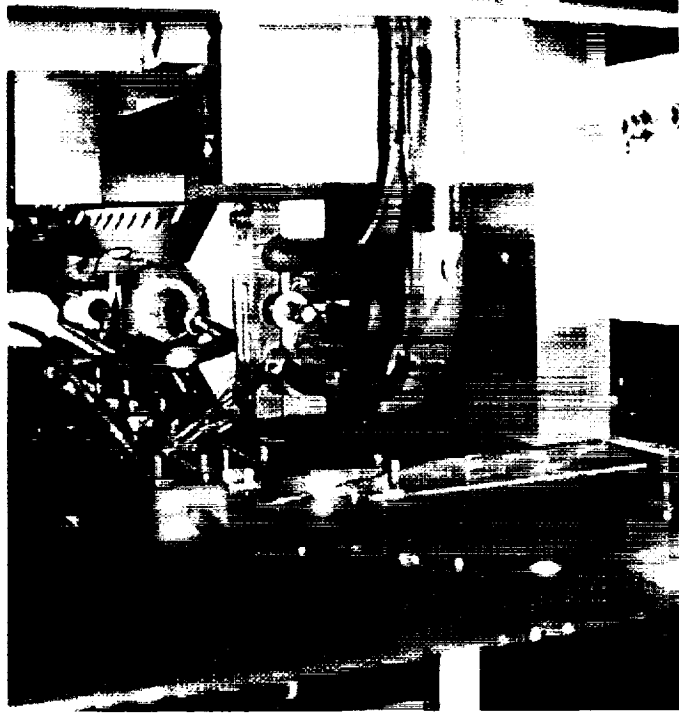
# DM LHP Test Design

- Two Mass Simulators linked to Two Al-NH3 HPs
- Single Mass Simulator (15 Kg) is actively powered to resemble 1 laser
- Double Mass Simulator (30 Kg) resembles 2 un-powered lasers
- Two HPs linked to Propylene LHP
- LHP Condenser flange bolted into two-sided radiator panel





# Starter Heater and Coupling Blocks

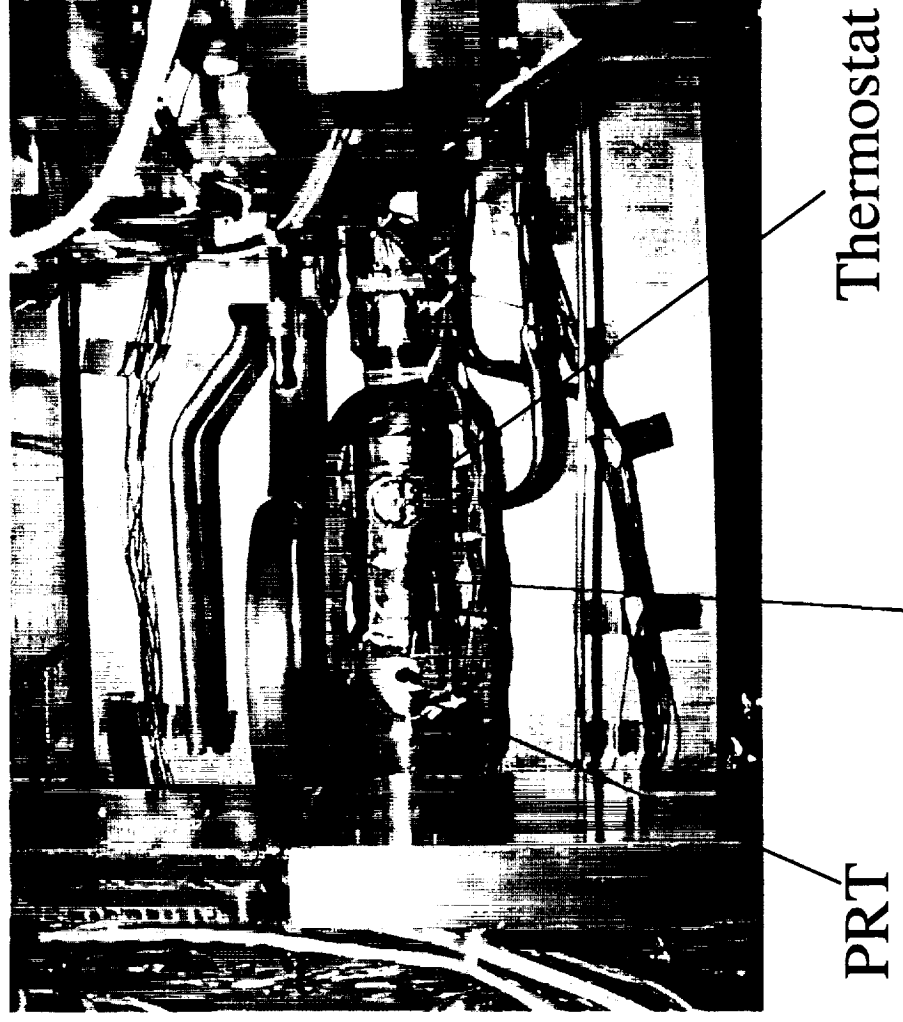
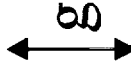


- Ten Al Blocks (1" long) couple Liquid and Vapor Lines
- Starter Htr is a Dale NHG-25 50 Ohm resistor footprint 0.56" x 1.1"
  - Heater was located 1" from end of evaporator (away from CC)
  - Startups were performed with 0, 15 and 20 W on heater



# CC Control Heaters and PRT

- Heaters were circumferentially wrapped around the middle of the CC
- PRT was used for control and placed along the centerline of the CC
- On/Off Controller setpoint was  $\pm 0.1^{\circ}\text{C}$
- Survival Thermostat had a setpoint from 0 to  $5^{\circ}\text{C}$

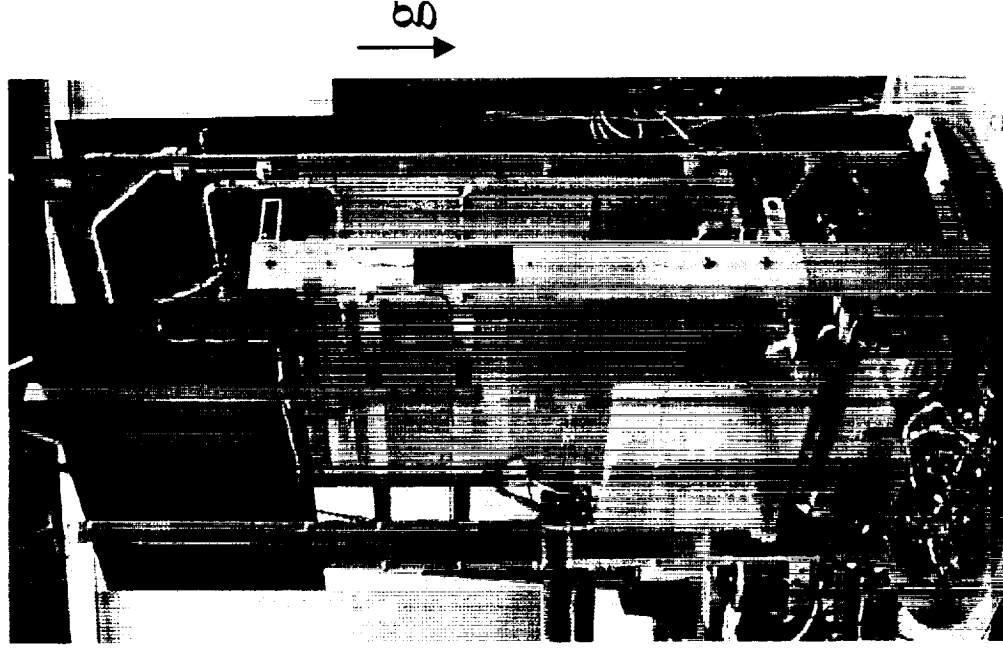


Circumferential Control Heaters



# Heater Plates (Shown in Reflux Mode)

- Two Heater Plates which viewed the radiator panel on one side and the  $-170^{\circ}\text{C}$  TV shroud on the other side were used to simulate the Flight Environment
- Plates were temperature controlled with large Kapton Heaters and painted black
- Plate Setpoints were correlated with Flight predicts
- Reflux mode (as shown) was defined as the majority of the vertical condenser above the evaporator (adverse is the opposite)
- Adverse height could be as high as 44"





# Startup Tests

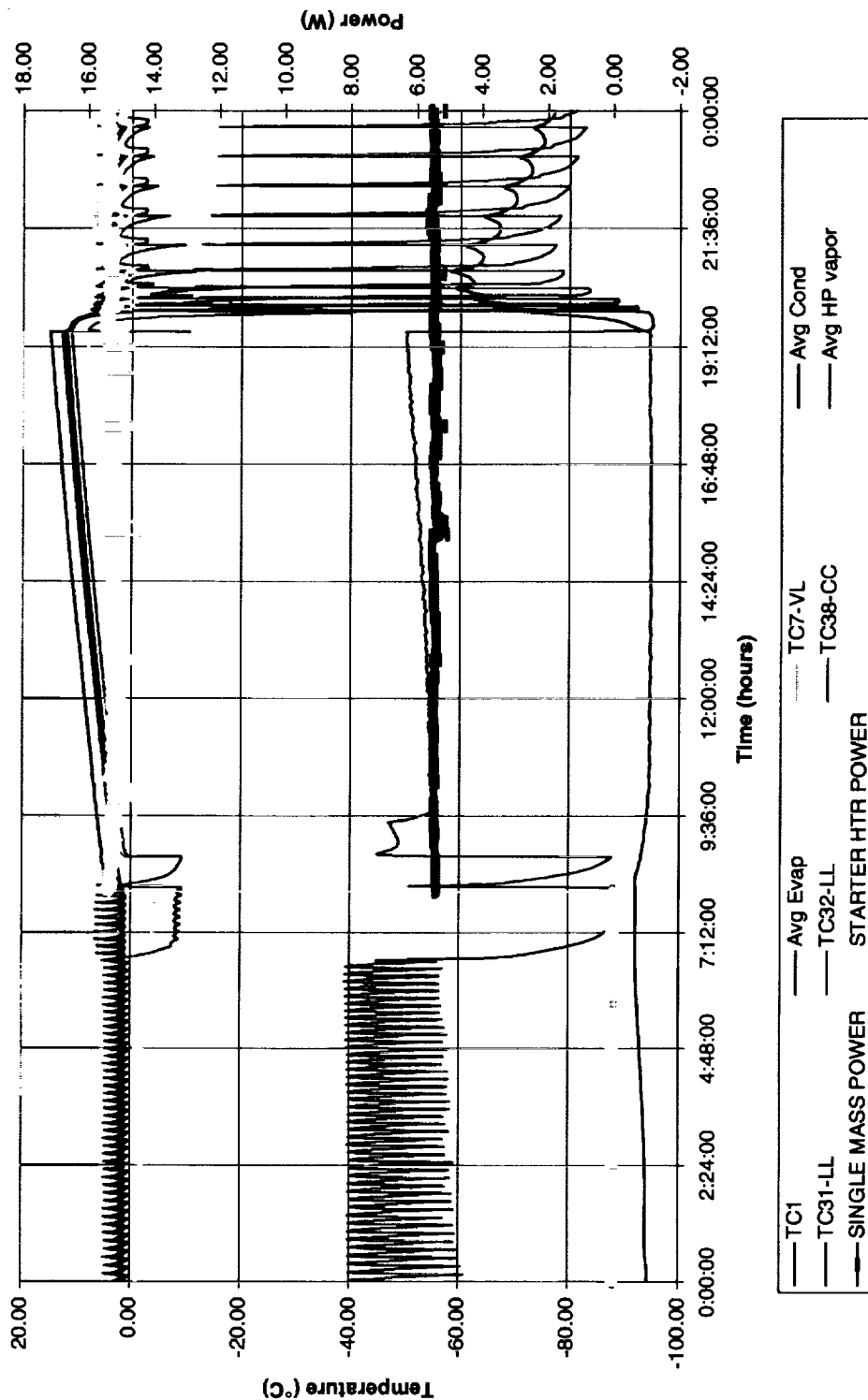
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- 17 Startups were performed with the following parameters:
    - Reflux versus Adverse Orientation (+44" vs -44")
    - 0 W, 15 W, 20 W of Starter Heater Power
    - Hot and Cold Survival Sink Conditions (-100 to -45°C Teff)
    - Various initial Evaporator and CC temperatures (0 to 25°C)
  - All startups were preceded by pre-heating the CC 3-5°C above the evaporator temperature
  - Verified need for starter heater for startup
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# Typical Cold Startup

DM LHP Thermal Vacuum Testing 9/28/99





# Startups: Effect of Orientation and Sink

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- Orientation (Adverse versus Reflux)

- 6 Startups performed in Reflux
- 11 Startups performed in Adverse
- Startups were similar in both orientations for
  - Time for Startup
  - Superheat at Startup (Max Evap Temp - CC Temp)
  - Maximum Evaporator Temperature

- Sink (Hot and Cold)

- No significant difference was seen between the Hot and Cold Sinks
  - Startup to Startup, the above parameters varied greatly
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# Startups: Effect of Starter Heater Power

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- Starter Heater Power
    - No Starter Heater Power
      - Even with 100 W on the Mass Simulator the LHP would not start without a starter heater (test stopped when 30°C reached)
    - 15 W vs 20 W of Starter Heater Power
      - The LHP started at similar evaporator temperature for either starter heater power on average (16.5°C)
      - The LHP required slightly higher superheat prior to startup for 20 W of Starter Heater Power on average (4.2 vs 3.5°C for 15 W)
      - The LHP required a longer startup time for 15 W of Starter Heater Power on average (18.5 vs 13.5 hours for 20 W)
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# Startups: Effect of Initial Evap Temp

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## •Effect of Initial Evap Temp

- All startups require the elapse of time and the evaporator reaching a high enough temperature
  - A high initial evaporator temperature still required time prior to startup, but less overall time than a cold initial evaporator temperature
  - The LHP always started before reaching 20°C as long as the evaporator was below 15°C initially
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# Startups: Repeatability

- Repeatability
  - 5 Similar Tests were conducted with 15 W on Starter Heater
  - 12 other tests had a variety of conditions (varied initial evaporator temperatures)

Startup Tests	# of Tests	Avg of Max TC 1 Temps	Std Dev of Max TC 1 Temps	Avg of Max Overall Evap Temps	Std Dev of Max Overall Evap Temps	Time for Startup (hours)	Std Dev of Time for Startup	Avg Superheat	Std Dev of Avg Superheat
All with Starter Heater (T0<20°C)	17	18.1°C	3.6°C	15.7°C	3.7°C	12:20	7:07	4.0°C	0.7°C
20 W Starter Heater Only	12	17.7°C	4.3°C	15.1°C	4.3°C	8:30	5:06	4.2°C	0.7°C
15 W Starter Heater Only	5	18.9°C	2.5°C	16.6°C	2.5°C	18:28	5:31	3.5°C	0.4°C



# CC Control Heater Power Tests for CC Temperature Control

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- Control Heater power can only be accurately measured in TV
  - GLAS DM LHP may be the first control heater power measurements in TV
  - 20 Control Heater Power Test measurements were performed with the following parameters:
    - Reflux versus Adverse Orientation
    - Hot and Cold Survival Sink Conditions and control setpoint
    - Mass Simulator Power (100 W, 120 W, 200 W)
    - Liquid-vapor Coupling blocks (8 vs 10 blocks)
    - Changing control setpoint (increasing and decreasing)
    - Measured temperature stability at mass simulator
  - All control heater power measurements were verified electronically and with a strip chart recorder
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# Heater Power: Effect of Orientation

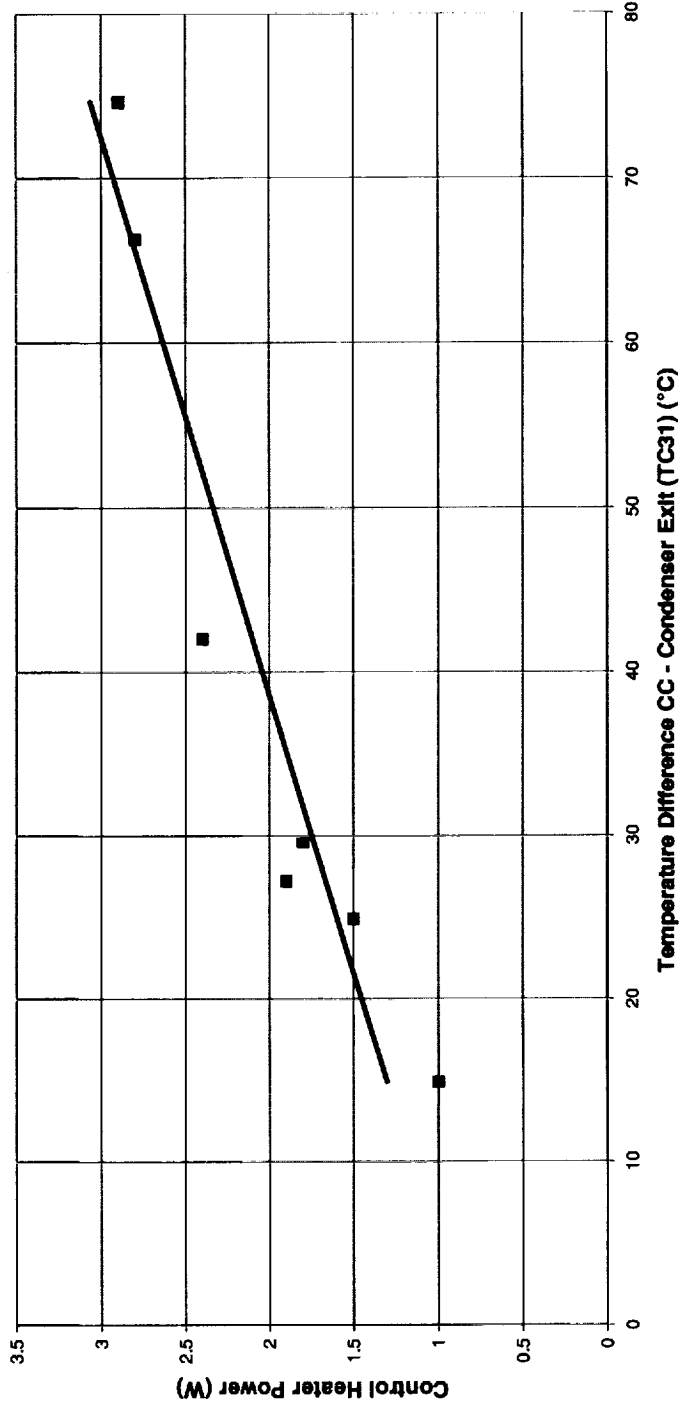
Test #	Reflux Orientation		Adverse Orientation		
	Power Required (W)	TC31	TC32	Test #	TC32
9	2.6	-66.	1.	14	1.
12	1.9	-20.	-3.	17	-1.
13	2.4	-27.	3.	18	5.

- Three comparable tests were performed in both the reflux and adverse
- Cold case Test 9 and Test 14 show no significant differences between the control power requirements between the orientations
- Hot Case Tests 12 and 13 and comparably 17 and 18 respectively
  - Control power differences can entirely be explained by the warmer liquid return temperatures (probably a warmer sink) as seen in TC32
- No significant differences in heater power are observed when comparing two orientations in the hot and cold sinks tested
- Note: TC31 is at the exit of the condenser, TC32 is after the liq/vapor coupling blocks



# Heater Power: Effect of Sink and Heater Setpoint

DM LHP Thermal Vacuum Testing  
Overall Control Heater Power for all 120 W Tests Only

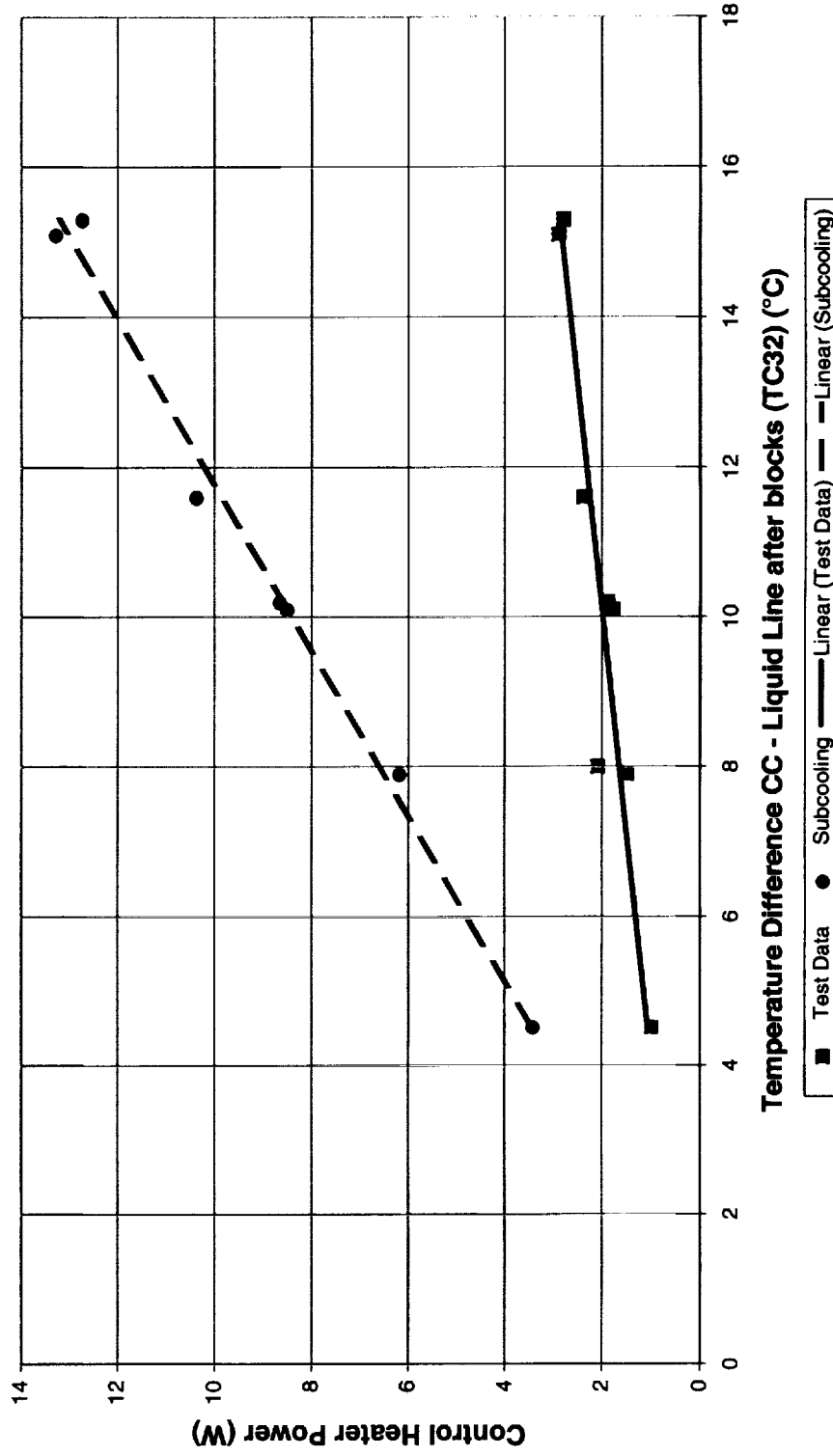


- CC setpoint were varied between 6.5 and 14.5 °C
- The greater the difference between the CC setpoint and the condenser exit temperature, the greater the control heater power requirement



# Heater Power: Comparison With Subcooling

DM LHP Thermal Vacuum Testing  
Overall Control Heater Power for all 120 W Tests Only





# Heater Power: Effect of # coupling blocks

- Coupling blocks had a fairly uniform coupling under a wide variety of input powers, sink conditions and orientations (Test 1 had 8 blocks, Test 3 to 20 had 10 blocks)
- Coupling blocks may be modelled as a fixed-conductance using a log mean temperature difference
- Variations in results cannot be explained with variations in test conditions
- Coupling was dominated by laminar film coefficient on liquid line
- Even with the enhanced coupling vs. laminar, the heater power requirement was  $\sim 1/3$  of model predictions

Test #	C per block (W/K)
1	0.079
3	0.081
9	0.092
10	0.097
11	0.088
12	0.070
13	0.090
14	0.084
15	0.077
16	0.088
17	0.081
18	0.099
19	0.101
20	0.072
avg	0.086
std dev	0.010
std dev/avg	0.113



# Heater Power: Effect of Evap Power

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- Control Heater Power was compared for a wide variety of applied evaporator powers: 100 W, 120 W, 201 W; the control heater power was independent of evaporator power in this range
  - This can only be explained through assuming that the CC is isolated from the liquid core and partly coupled to liquid return line
    - The CC is coupled to the liquid return through a fixed conductance (0.19 W/K-6" of coupling) as measured in heater power
    - Liquid return line had steady state Reynolds numbers below 2000
    - The heat leak through the wick is based primarily on the liquid return line temperature, not pressure losses in system
    - Mass flow rate must be adjusted for difference between sensible heat of liquid returned and actual control heater power based on fixed coupling
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# Heater Power: Changing Control Setpoint

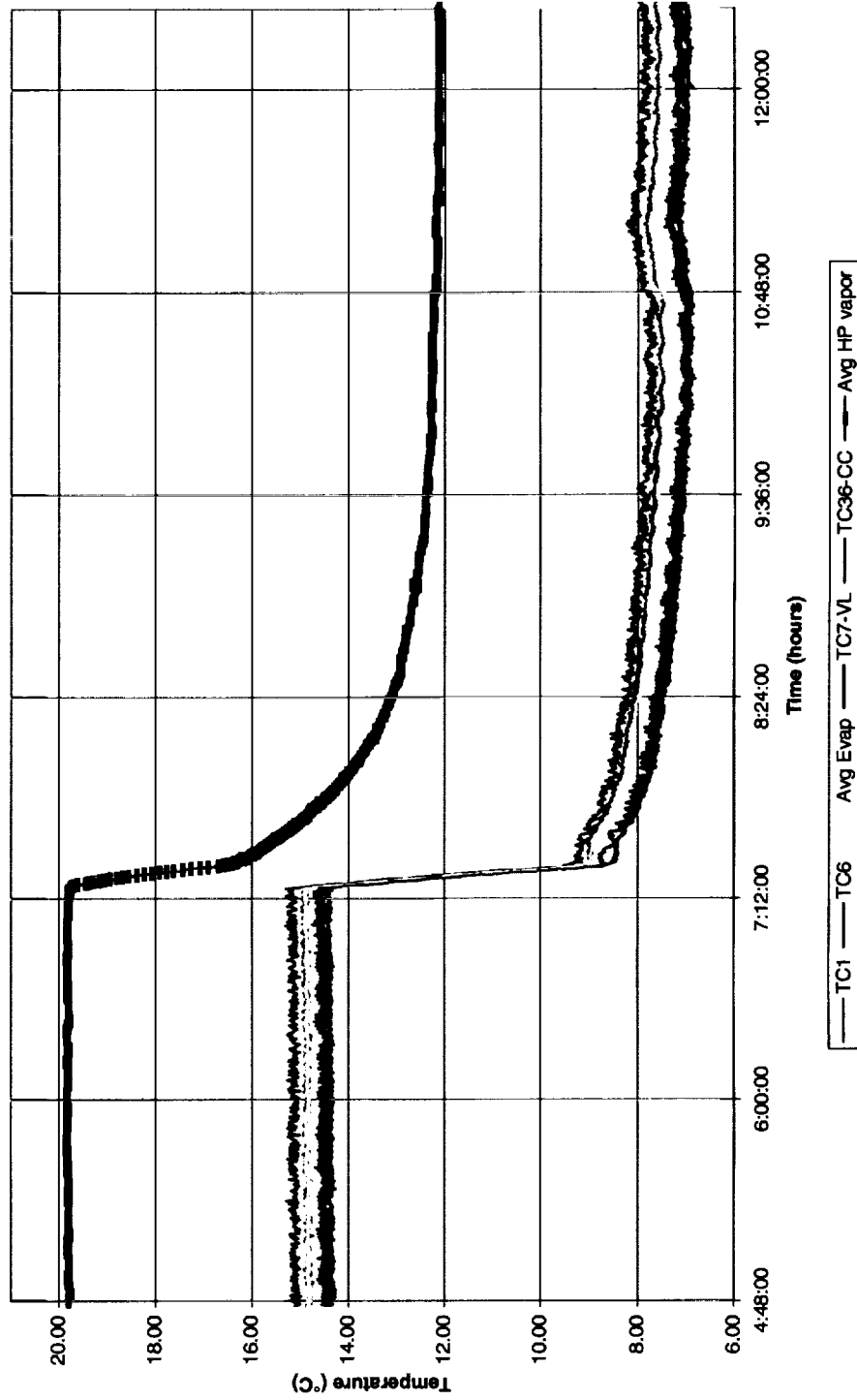
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- Raising the control setpoint results in diverting heat dissipation to sensibly heating the mass simulators
    - The fastest setpoint rise possible was 0.6°C/5 minutes without shutting down the LHP
    - If the starter heater is activated, the setpoint may be raised faster
  - No limitations were seen in the rate at which the setpoint is decreased 14°C at a step was attempted (LHP Un-controlled dropped 14°C in 30 minutes)
  - Stabilization times are on the order of hours
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# Control Temperature Stability

DM LHP Thermal Vacuum Testing 9/11/99  
Setpoint change from 14.5 to 6.°C at 120 W





# Conclusions

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- A starter heater is required for startup of large thermal mass propylene LHP systems (also verified by independent testing at JPL and Dynatherm)
  - Startup occurs after hours of time pass and the evaporator temperature rises to or above a “turn-over temperature” ( which results in the Delta-T or “superheat” required between Evaporator and CC)
  - Propylene LHP control heater power is solely a function of the difference between the liquid return line temperature and the CC setpoint times a constant conductance coupling
  - Utilizing liquid-vapor coupling blocks is a highly effective way to decrease control power without compromising control in the hot case
    - Test measured 1/3 of predicted control power requirement
  - Temperature control of a mass simulator is possible to  $\pm 0.1^{\circ}\text{C}$
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